

Magnetic-field effects on the charge-spin stripe order in La-214 high- T_c cuprates

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Abstract. Magnetic-field effects on the charge-spin stripe order in La-214 high- T_c cuprates have been investigated from measurements of the in-plane electrical-resistivity, ρ_{ab} . In $\text{La}_{2-x}\text{Ba}_x\text{CuO}_4$ with $x = 0.10$ and $\text{La}_{2-x}\text{Sr}_x\text{CuO}_4$ with $x = 0.115$ where the incommensurate charge peaks are weak and unobservable in zero field in elastic neutron-scattering measurements, respectively, the normal-state value of ρ_{ab} at low temperatures markedly increases with increasing field up to 27 T. For $\text{La}_{2-x}\text{Ba}_x\text{CuO}_4$ with $x = 0.11$ and Zn-substituted $\text{La}_{2-x}\text{Sr}_x\text{Cu}_{1-y}\text{Zn}_y\text{O}_4$ with $x = 0.115$ and $y = 0.02$ where the charge stripe order is fairly stabilized in zero field, on the other hand, the increase in ρ_{ab} with increasing field is negligibly small. In conclusion, when the charge-spin stripe order is not fully stable in zero field, magnetic field operates to stabilize the charge-spin stripe order. The value of ρ_{ab} increases with increasing field depending on the stability of the charge stripe order.

1. Introduction

These years, magnetic-field effects on the so-called charge-spin stripe order [1] in the La-214 high- T_c cuprates have attracted much attention. From elastic neutron-scattering measurements in $\text{La}_{2-x}\text{Sr}_x\text{CuO}_4$ (LSCO) with $x = 0.10$, it has been found that the intensity of the incommensurate magnetic peaks corresponding to the formation of the spin stripe order is enhanced with increasing field parallel to the c axis [2], suggesting the stabilization of the spin stripe order by the application of magnetic field. For LSCO with $x = 0.12$, on the other hand, the enhancement of the incommensurate magnetic peaks by the application of magnetic field is small [3], which is due to the fair stabilization of the spin stripe order even in zero field around $x \sim 1/8$. As for magnetic-field effects on the charge stripe order, elastic neutron-scattering measurements for $\text{La}_{1.6-x}\text{Nd}_{0.4}\text{Sr}_x\text{CuO}_4$ (LNSCO) with $x = 0.15$, in which the charge-spin stripe order is stabilized in the tetragonal low-temperature (TLT) structure (space group: $P4_2/nm$), have revealed no enhancement of the incommensurate charge peaks [4].

In order to investigate magnetic-field effects on the charge-spin stripe order from the viewpoint of transport properties, we previously measured the in-plane electrical resistivity, ρ_{ab} , in magnetic fields parallel to the c axis for $\text{La}_{2-x}\text{Ba}_x\text{CuO}_4$ (LBCO) with $x = 0.08, 0.10, 0.11$ and LNSCO with $x = 0.12$ [5,6]. It has been found for LBCO with $x = 0.10$ in the TLT phase that normal-state values of ρ_{ab} at low temperatures markedly increase by the application of magnetic

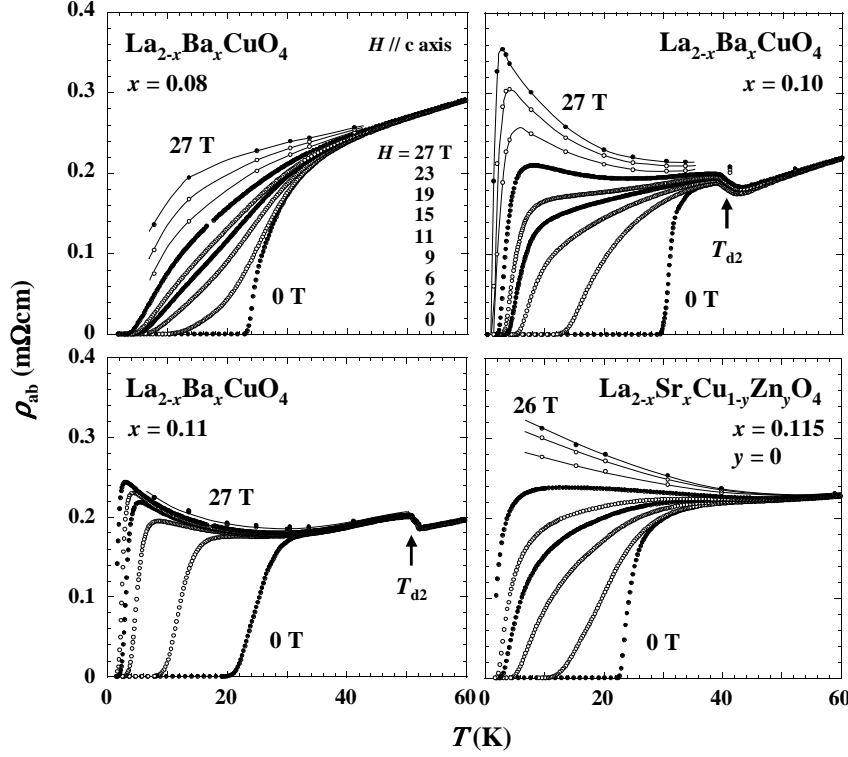


Figure 1. Temperature dependence of the in-plane electrical resistivity, ρ_{ab} , in various magnetic fields parallel to the c axis for $\text{La}_{2-x}\text{Sr}_x\text{Cu}_{1-y}\text{Zn}_y\text{O}_4$ with $x = 0.115$ and $y = 0$. The data of $\text{La}_{2-x}\text{Ba}_x\text{CuO}_4$ with $x = 0.08, 0.10, 0.11$ are also plotted for reference [5,6]. The temperature at which ρ_{ab} jumps corresponds to the structural phase transition temperature between OMT (see the text) and TLT phases, T_{d2} .

field. Since the incommensurate charge peaks are weaker at $x = 0.10$ than at $x \sim 1/8$ in LBCO [7,8], the result suggests that the charge stripe order is stabilized by the application of magnetic field, resulting in the change to an insulating behavior of ρ_{ab} .

In this paper, we investigate magnetic-field effects on ρ_{ab} in other La-214 systems, namely, $\text{La}_{2-x}\text{Sr}_x\text{Cu}_{1-y}\text{Zn}_y\text{O}_4$ (LSCZO) with $x = 0.115$ and $y = 0 - 0.02$. We discuss effects of nonmagnetic impurities and magnetic field on the charge-spin stripe order, using our previous results of LBCO with $x = 0.08, 0.10, 0.11$ also [5,6].

2. Experimental

Single crystals of LSCZO with $x = 0.115$ and $y = 0, 0.01, 0.02$ were grown by the traveling-solvent floating-zone method under flowing oxygen gas of 4 bar. The Sr and Zn contents were estimated by the inductively-coupled-plasma (ICP) measurements. Measurements of ρ_{ab} were performed in magnetic fields up to 27 T by a standard dc four-probe method, using a superconducting (SC) magnet below 15 T and a hybrid magnet above 15 T at the High Field Laboratory for Superconducting Materials (HFLSM), IMR, Tohoku University.

3. Results and Discussion

Figure 1 shows the temperature dependence of ρ_{ab} in various magnetic fields for LSCZO with $x = 0.115$ and $y = 0$ and also shows our previous results of LBCO with $x = 0.08, 0.10, 0.11$ [5,6].

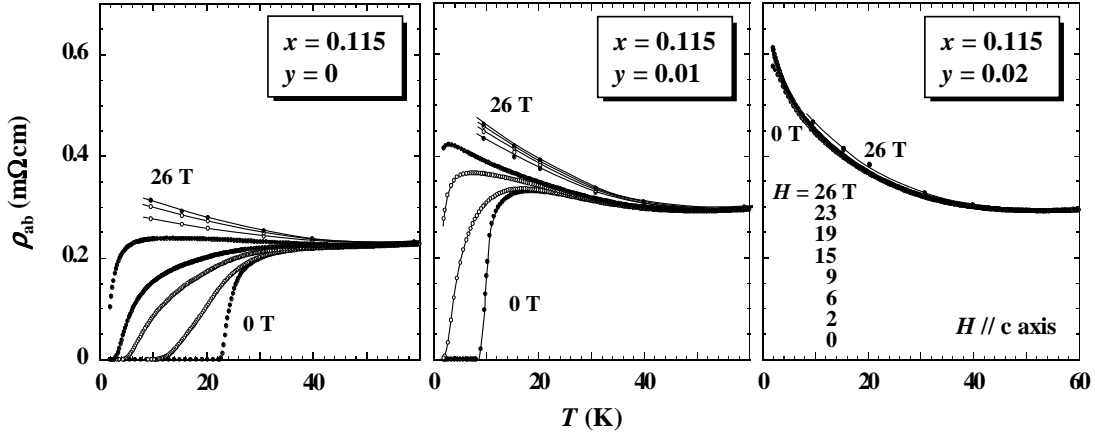


Figure 2. Temperature dependence of the in-plane electrical resistivity, ρ_{ab} , in various magnetic fields parallel to the c axis for $\text{La}_{2-x}\text{Sr}_x\text{Cu}_{1-y}\text{Zn}_y\text{O}_4$ with $x = 0.115$ and $y = 0, 0.01, 0.02$.

For LBCO with $x = 0.08$, the so-called fan-shape broadening is observed up to 27 T, which is characteristic of the underdoped high- T_c cuprates with large SC fluctuations. For LBCO with $x = 0.10$, the SC transition shows broadening in low fields and it shifts to the lower temperature side in parallel in high fields. Moreover, the normal-state value of ρ_{ab} at low temperatures increases with increasing field up to 27 T and an insulating behavior is observed in high fields. These suggest that the charge stripe order tends to be stabilized by the application of magnetic field up to 27 T. For LBCO with $x = 0.11$, on the other hand, the SC transition shows a parallel shift with increasing field and the increase in ρ_{ab} with increasing field is negligibly small. Similar magnetic-field effects on ρ_{ab} have been observed for LNSCO with $x = 0.12$ [5]. The robustness of ρ_{ab} against the applied magnetic field suggests that the stripe order is fairly stabilized even in zero field around $x = 1/8$.

As for LSCZO with $x = 0.115$ and $y = 0$, the broadening behavior of the SC transition at 2 T changes to be a parallel-shift behavior at 9 T and the normal-state value of ρ_{ab} at low temperatures increases with increasing field up to 26 T, resulting in an insulating behavior in high fields. Moreover, it is found that the overall behavior of the temperature dependence of ρ_{ab} in LSCO with $x = 0.115$ and $y = 0$ in each magnetic field is quite similar to that observed in LBCO with $x = 0.10$. In elastic neutron-scattering measurements in zero field for LSCO with $x \sim 1/8$, no incommensurate charge peaks have been observed in the orthorhombic mid-temperature (OMT) structure (space group: $Bmab$) [9]. Therefore, it is possible that the charge stripe order is stabilized by the application of magnetic field even for LSCZO with $x = 0.115$ and $y = 0$.

Figure 2 displays the temperature dependence of ρ_{ab} in various magnetic fields for LSCZO with $x = 0.115$ and $y = 0, 0.01, 0.02$. For $y = 0.01$, ρ_{ab} increases with increasing field at low temperatures and tends to be saturated at ~ 26 T. For $y = 0.02$, on the other hand, the increase in ρ_{ab} by the application of magnetic field is negligibly small up to 26 T, which is similar to the results of LBCO with $x = 0.11$ and LNSCO with $x = 0.12$. These suggest that the enhancement of ρ_{ab} with increasing field at low temperatures becomes weak with increasing Zn concentration and almost disappears for $y = 0.02$, which is consistent with our previous results of the thermal-conductivity measurements in magnetic fields for LSCZO around $x = 0.115$ [10,11].

It is well known that the normal-state value of ρ_{ab} in zero field increases with increasing Zn

concentration and a localized behavior appears at low temperatures in the underdoped high- T_c cuprates, as seen in Fig. 2. Although the magnetic field also affects carriers to be localized and ρ_{ab} shows an insulating behavior in the underdoped high- T_c cuprates [12], one cannot easily understand such significant magnetic-field effects on ρ_{ab} depending on the Zn concentration as shown in Fig. 2. Formerly, it has been suggested from zero-field muon-spin-relaxation (ZF- μ SR) measurements for LSCZO with $x = 0.115$ that Zn operates to pin the dynamical stripe correlations, leading to the formation of the static stripe order [13]. Moreover, the volume fraction of the spin-stripe-ordered region in a sample has been estimated to be ~ 90 % for $y = 0$ and 100 % for $y = 0.02$. Based upon these and the neutron-scattering results [9], the magnetic-field effects on ρ_{ab} for LSCZO with $x = 0.115$ can be interpreted as follows. That is, for $y = 0$, the charge stripe order is unstable in zero field, though the spin stripe order is stabilized in a sample. Accordingly, the charge stripe order is stabilized by the application of magnetic field, resulting in the increase in ρ_{ab} with increasing field. For $y = 0.01$, on the other hand, the charge-spin stripe order is pinned and rather stabilized by Zn, resulting in the weak magnetic-field effect on the stabilization of the stripe order. For $y = 0.02$, owing to the almost perfect stabilization of the stripe order by Zn, the magnetic-field effect on ρ_{ab} almost disappears. Therefore, it is concluded that both the magnetic field parallel to the c axis and Zn operate to stabilize the charge stripe order in La-214 high- T_c cuprates.

4. Summary

From ρ_{ab} measurements in magnetic fields for LSCZO with $x = 0.115$, it has turned out that the normal-state value of ρ_{ab} at low temperatures increases with increasing field for $y = 0$ in which the charge stripe order is unstable. Moreover, it has turned out that the enhancement of ρ_{ab} is negligibly small for $y = 0.02$ in which the charge stripe order is fairly stabilized by the substituted Zn. Taking into account our previous results of ρ_{ab} in magnetic fields for LBCO with $x = 0.08, 0.10, 0.11$, these results suggest that (i) the magnitude of the enhancement of ρ_{ab} by the application of magnetic field is in intimate relation with the stability of the charge stripe order in zero field and (ii) both the magnetic field parallel to the c axis and Zn operate to stabilize the charge stripe order in La-214 high- T_c cuprates.

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